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Comments on Correction Package Test Procedure

1. Introduction

The present test procedure asks that a correction package withstand all possible 50 amp current configurations without quenching. The measurements by Daniel Ciazynski and Paul Mantsch on the prototypes thus far indicate that the packages are "close" - either the criterion isn't quite met or it is barely met. By contrast, excitation of a single element of a package permits currents of 80 or more amps. So the question "how severe a problem is the observed behavior?" arises. Is it sufficiently likely to limit performance of the ED/S that the package should be redesigned?

The odds are strongly against finding that a given package be required to use all 50 amp combinations in operation. In fact, for long periods the relationships among the currents in a package will change rather little. Of course, we don't yet know what those relationships will be in detail, but some boundaries can be suggested that would lead to little risk. I will do so in the next section.

The correction package considered here contains concentric dipole, quadrupole, and sextupole windings. The integrated strengths are 170 KG-in, 60 KG, and 50 KG/in respectively at a current of 50 amps. The quadrupole and sextupole coils are identical in all of these packages, but the orientation of the dipole coil with relative to the others changes depending on whether the dipole steers horizontally or vertically.

2. Discussion of Current Ranges

(a) Quadrupoles

Consider tune shifting quads only. Let I(F), I(D) stand for currents in trim quads next to horizontally focusing and horizontally defocusing main quads respectively. Then to accomplish tune shifts dQH and dQV from the nominal operating point after having reached the operating point in the face of an average quad term in the dipoles of $\langle b1\rangle$ and a length excess in the main quads of dL implies

$$I(F)/E = 43*dQH + 12*dQV - 3.3*\langle b1\rangle - 18*dL$$

$$I(D)/E = 12*dQH + 43*dQV + 3.3*\langle b1\rangle - 18*dL$$

where the energy E is in units of TeV, b1 is in units of 1.0E-4/inch, and dL is in inches. A trim quad current is positive in sign if it strengthens the adjacent main quad.

The negative end of the range is easy - the trim quads are as strong as they are to hope to be able to compensate the effect on the tune of colliding beam low-beta interaction regions. Someday, the full -50 amps may be called for when a couple of low-beta insertions try to drive the tunes upward by one unit.

Use of the full positive range was not expected when the strengths were chosen. At high energy, we may want dQH = dQV = 0.225 for colliding beams in order to establish an operating point above the half-integer before turn on of interaction regions. Suppose that the absolute magnitude of <b1> may by 1.0 and take dL=-0.25 inch. Then we would have a maximum positive current of 20 amps at E=1.0.

From the foregoing, the trim quad currents could reasonably be expected to lie in the range from -50 amps to +20 amps.

(b) Sextupoles

Consider chromaticity adjustment only. The notation for the currents is the same as in (a) above. Let CH and CV denote the horizontal and vertical chromaticities. Let RH and RV be the factors by which the natural values of CH and CV are enhanced (made more negative) by colliding beam interaction regions. Then to obtain chromaticities CH and CV in the face of a sextupole term <b2> requires

I(F)/E = 0.163*CH + 0.047*CV - 3.2*<b2> + 3.6*RH + 1.0*RV

I(D)/E = 0.087*CH + 0.30*CV + 5.1*<b2> + 2.0*RH + 6.7*RV

where b2 is in units of 1.0E-4/in**2.

The strength of the sextupoles was set to permit -6 < <b2> < 6. It looks like the sextupole moment is being controlled on the average somewhat better than that. Assume for now that we can specify <b2> and end up with a result within 2 units in either direction.

For the insertions described in the Design Report, the largest values of RH and RV are 1.3. For two interaction regions, we take RH = RV = 1.6. I can't think of any reason why a chromaticity large in magnitude would be useful, so I take a range of -22 to +22; i.e., sufficient to reverse the natural chromaticity, as has been shown by Mike Harrison to be of value for extraction.

With the presumptions above, the current maxima are

I(F)/E = 18.3 - 3.2*b ; I(D)/E = 32.7 + 5.1*b

and the minima are

I(F)/E = -6.3 - 3.2*b ; I(D)/E =-10.1 + 5.1*b

where b is the target value of <b2>.

The range of I(F)/E is therefore 25 amps, and that of I(D)/E is 43 amps. For -1.7<b<0.5, the range of I(F) is contained within that of I(D). For example, if the target value of b were -1.5, the sextupole currents would be less than 25 amps in magnitude.

(c) Dipoles

When the quadrupoles and sextupoles are at high excitation, the typical dipole, in its role as orbit corrector, will be carrying a relatively low current. Here, it is a question of how far out in the distribution one wants to go, while recognizing that there may be a small percentage of elements demanding higher excitation (and so possibly requiring training).

As noted in the Design Report, if we take 0.02 inches for the rms quadrupole alignment error and 1.4E-3 for the fractional error in the dipole field or roll angle, then the rms value of the steering dipole field integral would be 41 KG-in. For a 90% chance of successful correction at 100 stations about "3.2 sigma" is needed, or 130 KG-in. Given the uncertainty in the 41 KG-in figure, the full steering dipole strength may be required at certain locations during initial high energy operation.

It is quite a different thing to insist that all steering dipoles run up to maximum current while the other coils are carrying substantial current. At that stage (colliding beams, slow extraction) dipole excitations will have stabilized and the larger values reduced due to corrective measures. Then I think a "2 sigma" requirement should be acceptable - that is, all dipoles should be capable of 25 amp excitation of either sign when the other magnets are powered to the levels indicated in (a) and (b) above. If no corrective measures such as magnet alignment or replacement are taken, then 5% of the dipoles, on the average, would require currents above 25 amps. Some training may then be necessary at the locations involved.

3. Summary

It is recommended that correction package performance be examined with simultaneous excitations in the ranges

Dipole	-25 to +25 amps
Quadrupole	-50 to +20 amps
Sextupole	-25 to +25 amps

The sextupole range above implies a target value for <b2> of -1.5E-4/in**2; other ranges would be associated with other values of the average sextupole term in the main dipoles.

I still think it important that when powered individually the elements achieve 50 amps with ease.